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Topic 1 – Introduction

EE-4382 Antenna Engineering

Outline

- Introduction
- Types of Antennas
- Radiation Mechanism
- Mathematical Preliminaries
- Antenna Parameters
- Communications Link

Constantine A. Balanis, *Antenna Theory*, 3rd Ed., Wiley, 2005.

Introduction

What is an Antenna?

Merriam-Webster:
A usually metallic device (such as a rod or wire) for radiating and receiving radio waves.

IEEE:
The part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves.

Constantine A. Balanis:
The transitional structure between free-space and a guiding device.

What do Antennas Do?

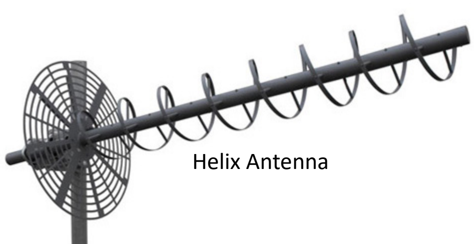
- Convert between guided wave and external propagating wave
- Shape the radiation pattern
- Control polarization
- Cooperate with other antennas

Types of Antennas

Antenna Categories

- Thin wire antennas
- Aperture antennas
- Microstrip antennas
- Array antennas
- Reflector antennas
- Lens antennas

Wire Antennas

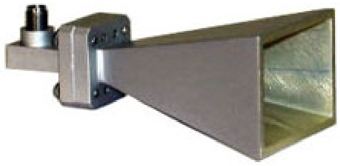


Helix Antenna

Dipole Antenna

Loop Antenna

Aperture Antennas

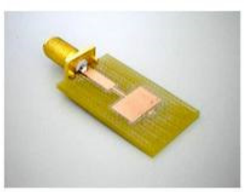


Pyramidal Horn

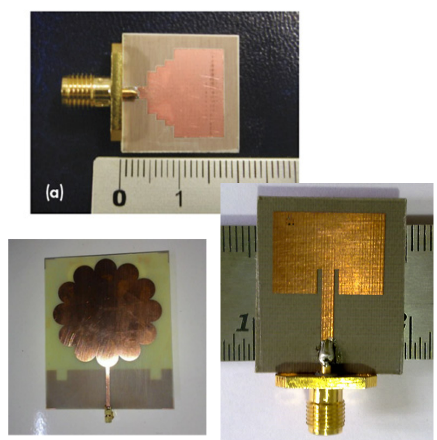
Rectangular Waveguide

Conical Horn

Microstrip Antennas



Rectangular Patch



Other Variants

Circular Patch

Array Antennas

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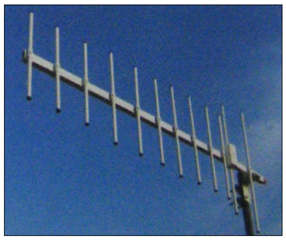
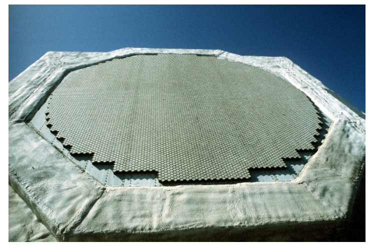
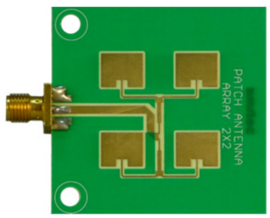


Yagi-Uda



Phased Array



Patch Array

Slotted Waveguide

Introduction to Antennas

Slide 11

Reflector Antennas

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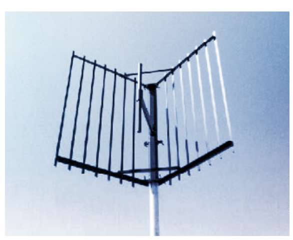

Reflector Grid

Parabolic Dishes

Corner Reflector

Introduction to Antennas

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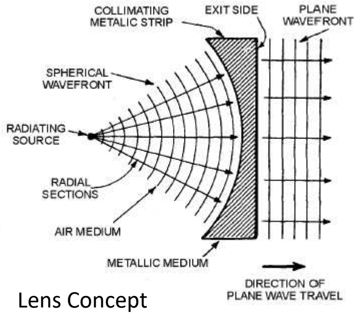
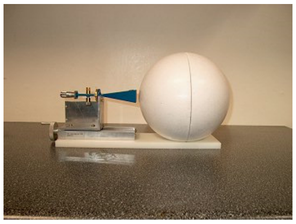
Lens Antennas



Lens Concept


Conical Horns + Lens

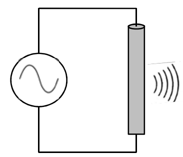

Ball Lens

Radiation Mechanism

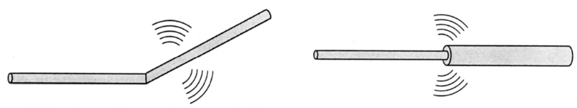
Fundamental Mechanism

For radiation to occur, you must have:

1. Time-varying current.



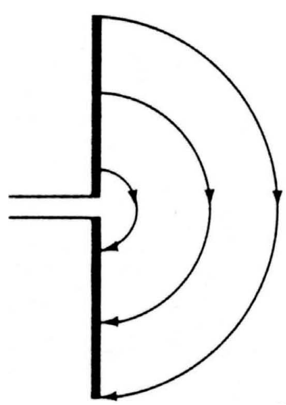
2. Acceleration (or deceleration) of charge.



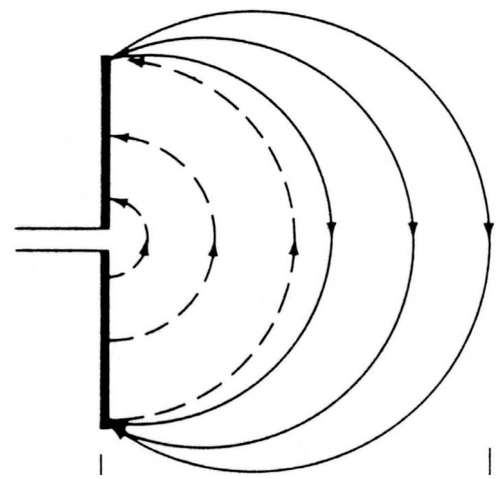
Bent wire

Discontinuous wire

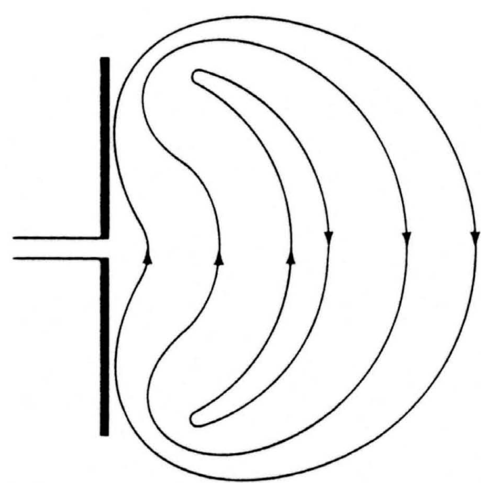
Detachment Mechanism (1 of 3)



Detachment Mechanism (1 of 3)

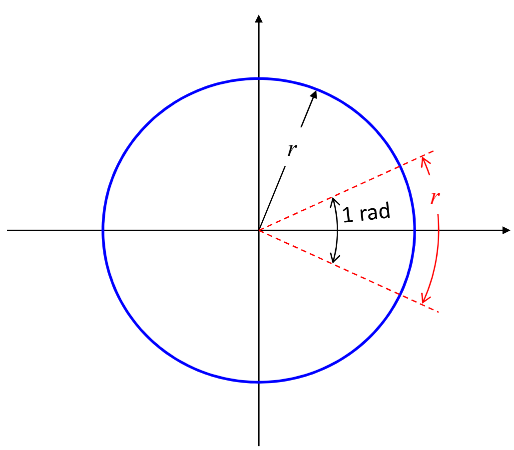


Detachment Mechanism (1 of 3)

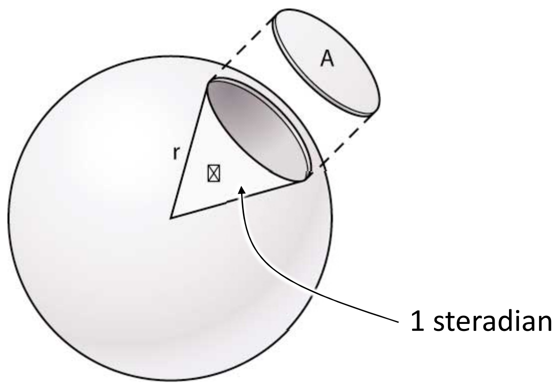


Mathematical Preliminaries

Radians



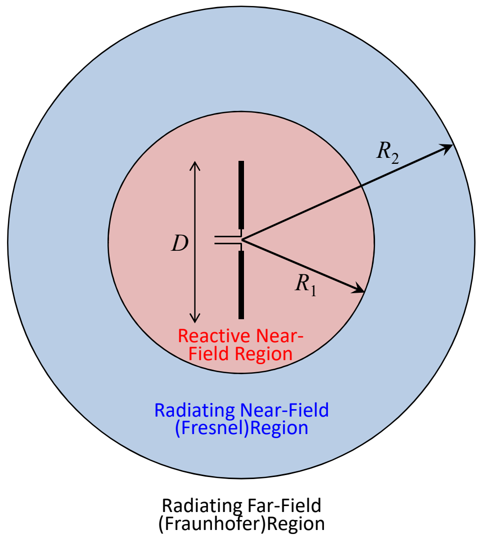
Steradian



$$A = r^2$$

Antenna Parameters

Field Regions (1 of 3)



$$R_1 \cong 0.62\sqrt{\frac{D^3}{\lambda}}$$

$$R_2 \cong 2\frac{D^2}{\lambda}$$

Field Regions (2 of 3)

- Reactive Near-Field
  - Phase of E and H near quadrature (i.e. 90°)
  - Highly reactive wave impedance
  - High content of non-propagating stored energy
- Radiating Near-Field
  - E and H predominantly in phase (i.e. 0°)
  - Waves do not yet have spherical wavefront and so pattern varies with distance
- Radiating Far-Field
  - Waves have spherical wavefront and so pattern remains uniform with distance
  - E and H are in phase (i.e. 0°)
  - Wave impedance is real
  - Power predominately real because it is propagating

Field Regions (3 of 3)

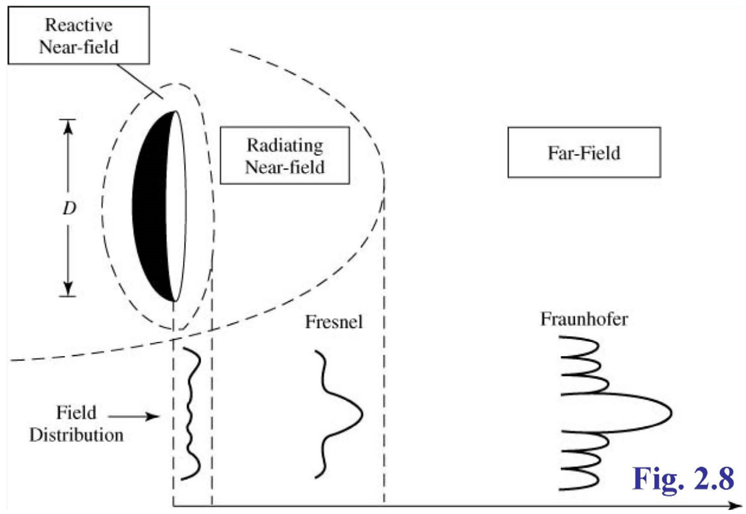
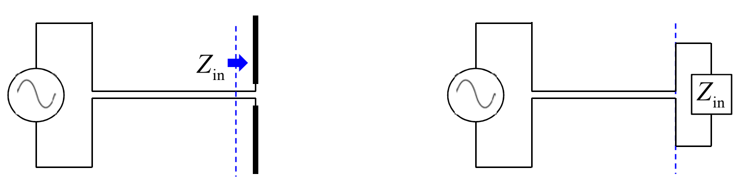


Fig. 2.8

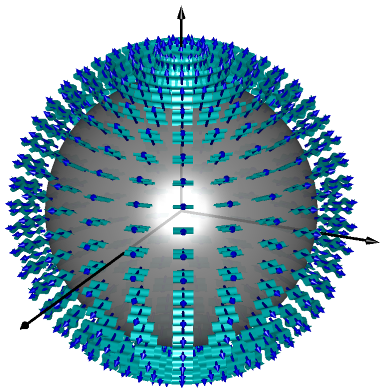
Input Impedance, Z_{in}

To an electrical circuit, an antenna just look like a lumped impedance element. The impedance seen by the circuit is the input impedance of the antenna.



The Isotropic Radiator

Perfectly isotropic radiation is impossible in practice, but we can talk about it mathematically.



Power Density

$$W_0 = \frac{P_{\text{rad}}}{4\pi r^2} \left(\frac{\text{W}}{\text{m}^2}\right)$$

$P_{\text{rad}} \equiv$ total power radiated by source

Sources look dimmer from farther away. Power density is this metric.

Radiation Intensity

$$U_0 = \frac{P}{4\pi} \left(\frac{\text{W}}{\text{Sr}}\right)$$

Even though sources look dimmer from farther away, the power they are putting out does not change. Radiation intensity is this metric.

Radiation Pattern

A line or surface quantifying the radiation properties of an antenna as a function of direction, usually θ and ϕ. Usually, this is relative to the ideal isotropic radiator.

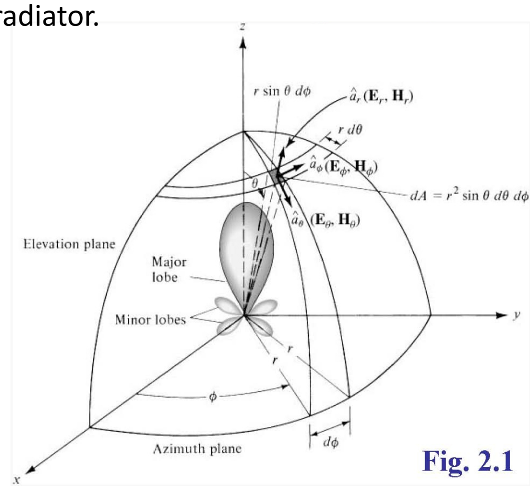
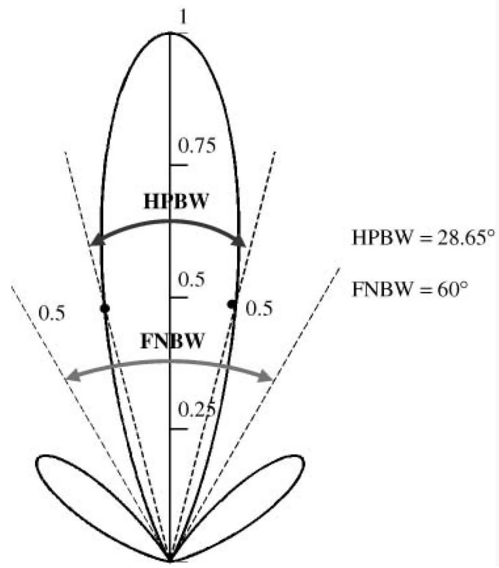


Fig. 2.1

HPBW and FNBW

We need metrics to characterize the main beam from an antenna. Two common metrics are the *half-power beam width* (HPBW) and the *first null beam width* (FNBW).



Directivity, D

An antenna can enhance how much of a signal it transmits in one direction by transmitting less in another direction.

Directivity is a measure of how directional an antenna's radiation pattern is.

The isotropic radiator has zero directionality and so $D = 1$ (or 0 dB).

$$D = \frac{4\pi}{P_{\text{rad}}} U(\theta, \phi)$$ Linear directivity

$$D\ (\text{dB}) = 10 \log_{10} D$$ Logarithmic directivity

Antenna Efficiency, ξ

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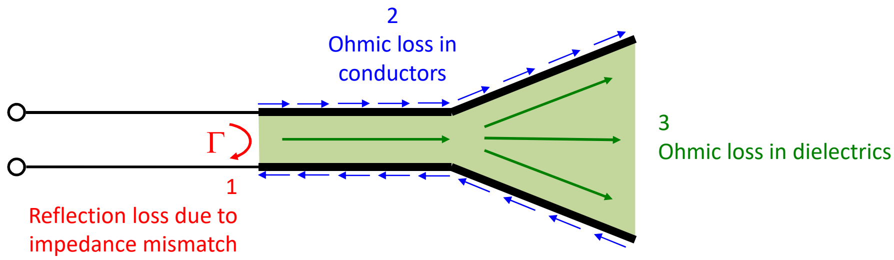

$$\xi_0 = \underbrace{\xi_\Gamma \xi_\sigma \xi_\varepsilon}_{} \equiv \text{total radiation efficiency}$$

Radiation Efficiency

$$\xi_{\text{rad}} = \xi_\sigma \xi_\varepsilon$$

Reflection Efficiency

$$\xi_\Gamma = 1 - |\Gamma|^2$$

Antenna Gain, G (1 of 2)

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Consider what can happen to a signal when applied to an antenna.

1. **Mismatch** – Part of the signal may be reflected back to the source due to an impedance mismatch to the antenna.
2. **Efficiency** – Part of the signal may be absorbed due to ohmic loss.
3. **Directivity** – Different parts of the signal may be radiated in different directions.

Gain is the quantity that accounts for all of these and it is expressed relative to the 100% efficient isotropic radiator.

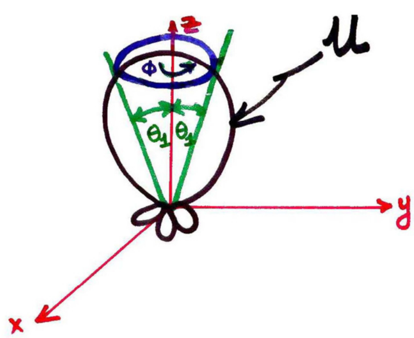
Usually antennas are well impedance-matched and the efficiency is high and gain mostly conveys directivity. Many people are incorrectly conditioned to think gain is only directivity.

Antenna Gain, G (2 of 2)

$$G \equiv 4\pi \frac{\text{radiation intensity}}{\text{total accepted power}}$$
$$= (\text{radiation efficiency})(\text{directivity})$$
$$= \xi_{\text{rad}} D$$
$$= \xi_{\sigma} \xi_{\varepsilon} \frac{4\pi}{P_{\text{rad}}} U(\theta, \phi)$$

Note: Mismatch loss is not included in gain.

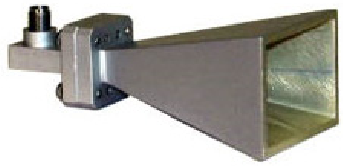
Beam Efficiency, BE

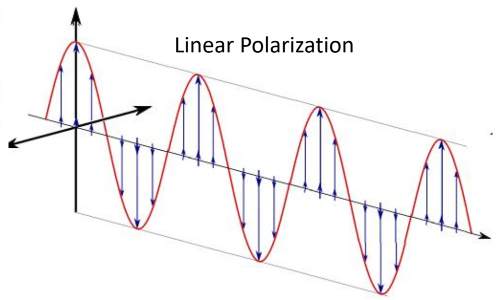


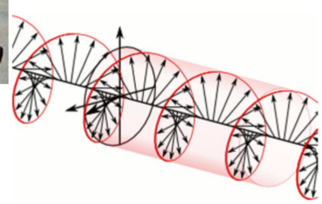
$$\text{BE} = \frac{\text{total power in main beam}}{\text{total radiated power}}$$
$$= \frac{\int_0^{2\pi} \int_0^{\theta_1} U(\theta, \phi) \sin\theta \, d\theta \, d\phi}{\int_0^{2\pi} \int_0^{\pi} U(\theta, \phi) \sin\theta \, d\theta \, d\phi}$$

Polarization

Different antennas will transmit/receive different polarizations.







Polarization Loss Factor, PLF

Suppose a wave with polarization vector $\hat{p}_{\text{inc}}$ is incident onto an antenna designed to receive waves with polarization vector $\hat{p}_{\text{ant}}$.

If these two polarizations are not matched, some portion of the signal will not be received.

perfect mismatch

perfect match

$$\text{PLF} = \left|\hat{p}_{\text{inc}} \bullet \hat{p}_{\text{ant}}\right|^2 \qquad 0 \le \text{PLF} \le 1$$

$$\text{PLF}\ \ (\text{dB}) = 20\log_{10}\left|\hat{p}_{\text{inc}} \bullet \hat{p}_{\text{ant}}\right| \qquad -\infty \le \text{PLF}\ \ (\text{dB}) \le 0$$

Communications Link

Friis Transmission Equation

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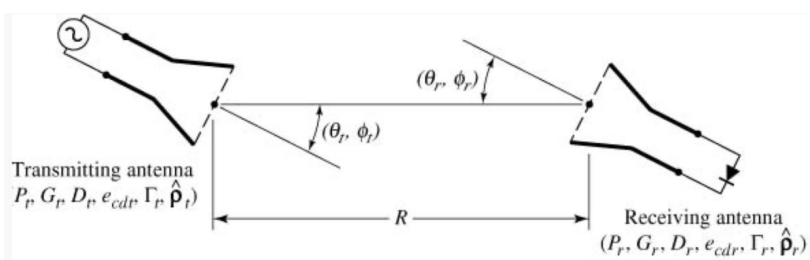

$$\frac{P_\mathrm{r}}{P_\mathrm{t}} = \left(1-\left|\Gamma_\mathrm{t}\right|^2\right)\cdot\left(1-\left|\Gamma_\mathrm{r}\right|^2\right)\cdot\left(\frac{\lambda}{4\pi R}\right)^2\cdot G_\mathrm{t}\cdot G_\mathrm{r}\cdot \mathrm{PLF}$$

- Loss due to impedance mismatch at transmitter.
- Loss due to impedance mismatch at receiver.
- Propagation loss factor
- Gain of transmitting antenna
- Gain of receiving antenna
- Polarization loss factor